Possible mechanism of the increase in solar irradiance cloud transmittance and decrease in cloud cover over Europe due to negative trends in sulphate aerosols: a study with the INMCM5 climate model

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Abstract: We showed that according to the Era-Interim re-analysis data there is a pronounced cloud radiative transmittance increase over Europe during warm period since the end of 1970s (Chubarova et al., 2020).

In this study using the reconstruction model and routine cloud observations we demonstrate that the main reason of these changes is the decrease in low layer cloud cover and not the effect of cloud optical thickness change.

At the same time, there is a pronounced negative trend in sulphate aerosol optical thickness over this period in this region.

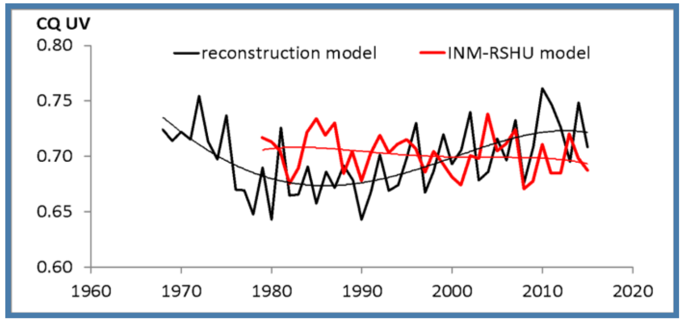
Using INM RAS model with 2 x 1.5° resolution (Volodin et al., 2017) we made several numerical experiments for evaluating the possible role of indirect effects of hydrophilic sulphate aerosols on solar irradiance cloud transmittance trends.

The results have revealed that during warm period the account for non- direct aerosol effect provides a better agreement in simulated cloud solar irradiance transmittance trends over Europe with those obtained from the Era-Interim reanalysis data and reconstruction model.

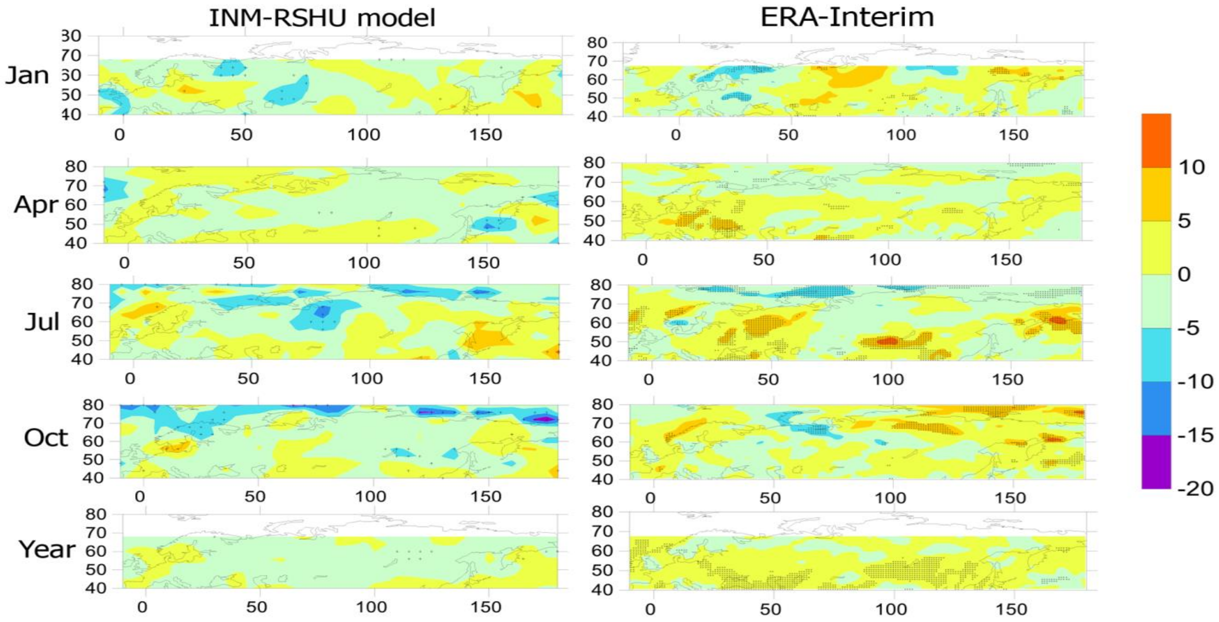
Problems:

Problems with solar irradiance trend retrievals in different CCMs (Lamy et al., 2018, Wang et. al., 2015, Chubarova et al., 2020) ….

Variability of UV cloud radiative transmittance in Moscow according to INM-RHSU CCM and model of reconstruction in UV spectral region. (Chubarova et al., 2018)



The changes in radiation due to cloud transmittance 2000-2015гг. compared with 1979-1999 according to INM-RSHU CCM and ERA-Interim reanalysis (Chubarova et al., 2020)



Tasks:

- **To assess the response of solar irradiance to different factors (aerosol and cloudiness) using the updated reconstruction model;**

- **To estimate the non- direct aerosol effect on cloud radiative transmittance trends in INM-RHSU CCM**

Model of reconstruction and its testing against long-term measurements at Meteorological Observatory of Moscow State University.

Aerosol factor | Cloud amount factor | Cloud optical thickness factor

$$V_i = \frac{\sum_j (W_j(h)\ (v1_{i,j}(\tau_a, P_{cf}, A) + v2_{i,j}(CQ_A, A) + v3_{i,j}(\tau_c, P_{ov}, A))}{\sum_j W_j(h)}$$

W(h) – solar elevation weighting function
i – index for year
j – index for month

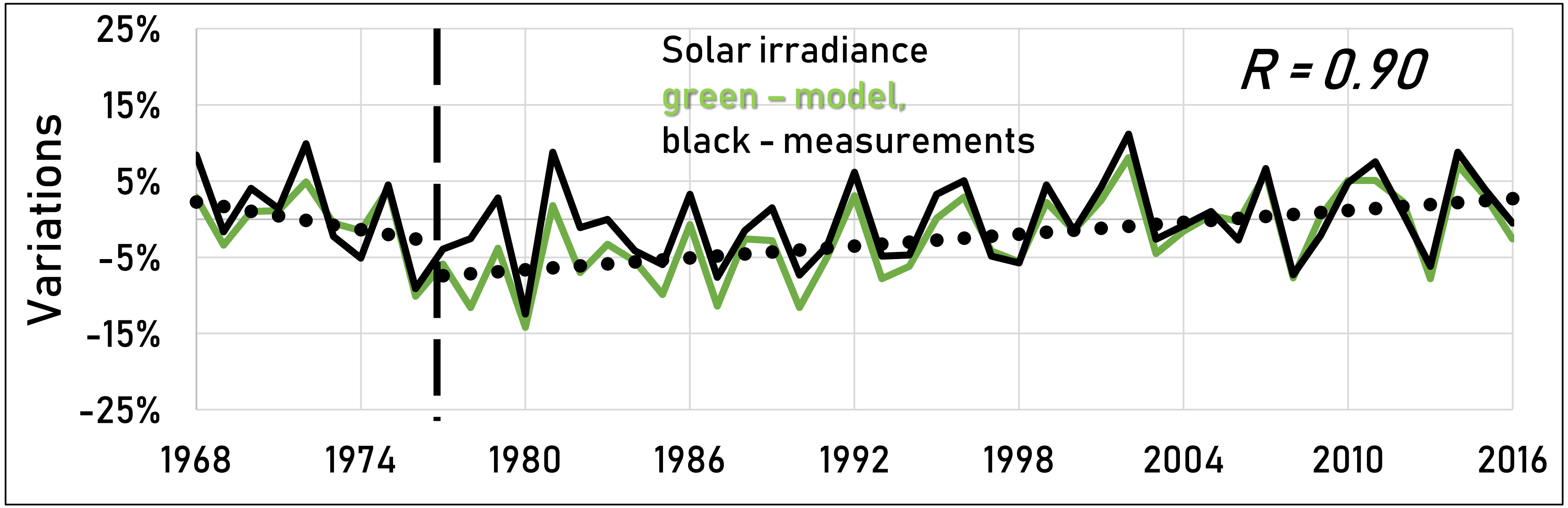
updated from Chubarova 2008, ACP

$$CQ_A = \frac{CQ_{A=0}}{(1 - A(C - D\ CQ_{A=0}))}$$

$$CQ_{A=0} = \sum_{Nl=0}^{10} \{[P(Nl) - P(Nl, N_{10})] \times CQ_{A=0}(Nl) + P(Nl, N_{10}) \times CQ_{A=0}(Nl) \times CQ_{up}\}$$

v1	**Aerosol factor**
τ_a	AOD
P_{cf}	Frequency of quasi-clear sky
A	Surface albedo
v2	**Cloud amount factor**
CQ_A	Effective radiative transmittance due to cloud amount with account of albedo
v3	**Cloud optical thickness factor**
τc	Cloud optical thickness
P_{ov}	Frequency of overcast cloud conditions

Model testing:



Linear trends for two periods:

1968-1976	-4.9%±1.1% per decade
1977-2016	+2.5% ±0.9% per decade

- measurements, WRDC
- model reconstruction
- due to effective cloud amount
- due to aerosol optical thickness
- trend(CQ_1979)
- trend(AOT_2000)

The examples of long-term variations in solar irradiance due to effective cloud amount and aerosol using reconstruction model and WRDC/GAW measurements

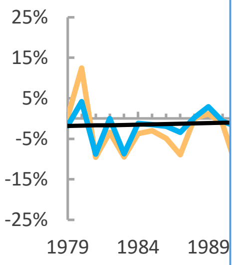
[w ... old period]

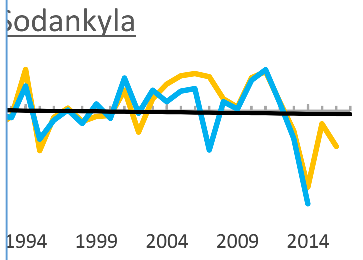
There is a good agreement between observed solar irradiance changes and effective cloud amount (r=0.73-0.92 for warm period and r=0.64-0.77 – for cold period) in different regions.
Aerosol account provides a small improvement.

Northern European region

due to CQ since 1979: +0.7% ± 0.3% / decade
due to AOT since 2000: +1.5% ± 0.4% / decade

R1979(cq+wrdc) = 0.85
R2000(cq&aot+wrdc) = 0.88

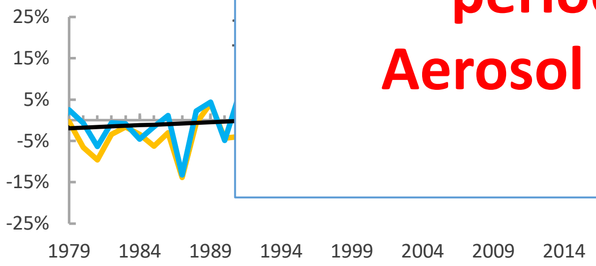




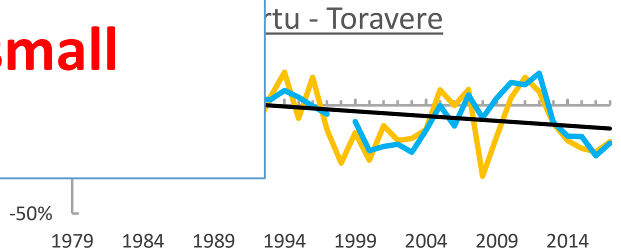
Central European region

due to CQ since 1979: +1.4% ± 0.5% / decade
due to AOT since 2000: +0.4% ± 0.1% / decade

R1979(cq+wrdc) = 0.73
R2000(cq&aot+wrdc) = 0.79



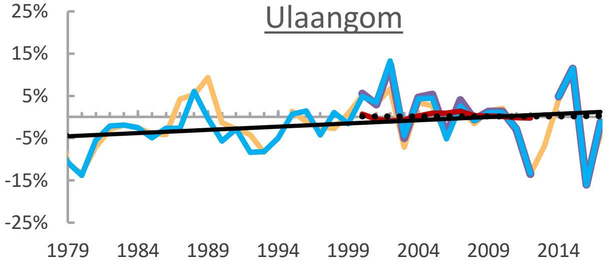
R1979(cq+wrdc) = 0.77



Central Asia

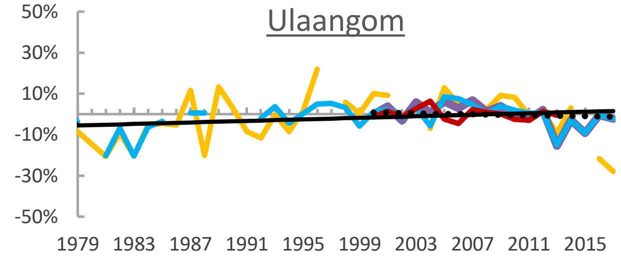
due to CQ since 1979: +1.5% ± 0.6% / decade
due to AOT since 2000: +0.04% ± 0.01% / decade

R1979(cq+wrdc) = 0.92
R2000(cq&aot+wrdc) = 0.98



due to CQ since 1979: +1.9% ± 0.7% / decade
due to AOT since 2000: -1.2% ± 0.3% / decade

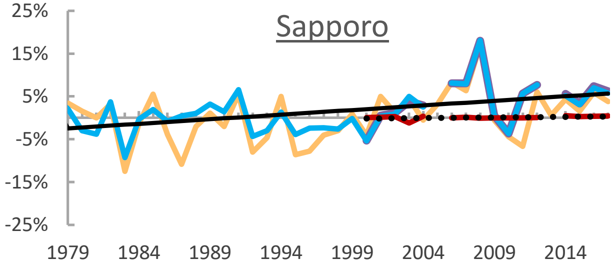
R1979(cq+wrdc) = 0.64
R2000(cq&aot+wrdc) = 0.47



Pacific region

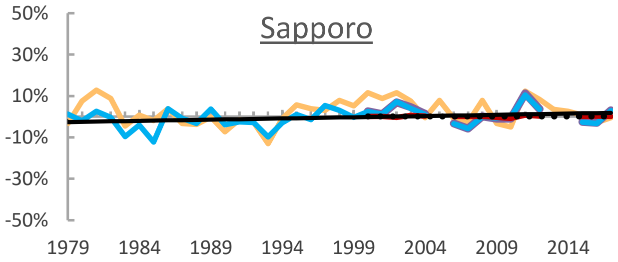
due to CQ since 1979: +2.4% ± 0.8% / decade
due to AOT since 2000: +0.3% ± 0.1% / decade

R1979(cq+wrdc) = 0.86
R2000(cq&aot+wrdc) = 0.95



due to CQ since 1979: % ± 0.5% / decade
due to AOT since 2000: +0.04% ± 0.01% / decade

R1979(cq+wrdc) = 0.70
R2000(cq&aot+wrdc) = 0.79



Estimation of sensitivity in cloud radiative transmittance to different emissions of aerosol precursors in 1980 and 2005 due to aerosol-cloud interaction according to INMCM5 (Volodin et al., 2017) numerical experiments.

control experiment – 10 model year :

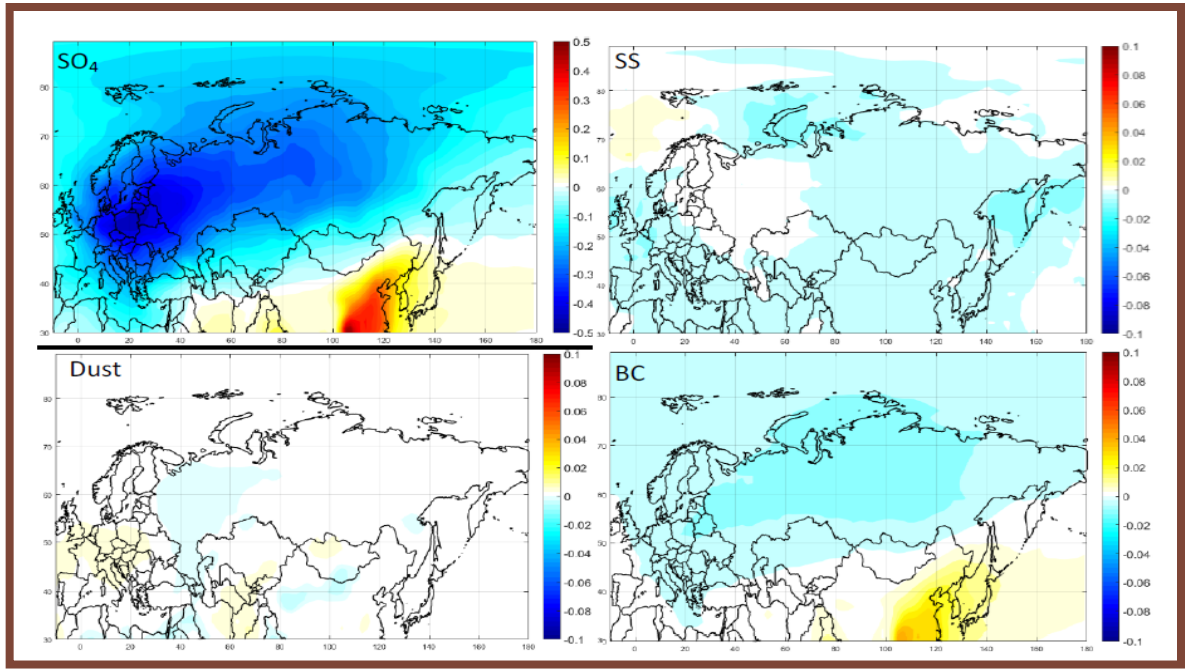
$$N_d = \exp(4.86 + 0.0\ \ln M_{aerosol})$$

experiment with aerosol –cloud interaction- 10 model years:

$$N_d = \exp(4.86 + 0.41\ \ln M_{aerosol})$$

[McCoy et al. 2017]

Difference between 2005 and 1980 in model AOD of sulphate (SO4), SS, DU, BC aerosol types according to INMCM5 model.



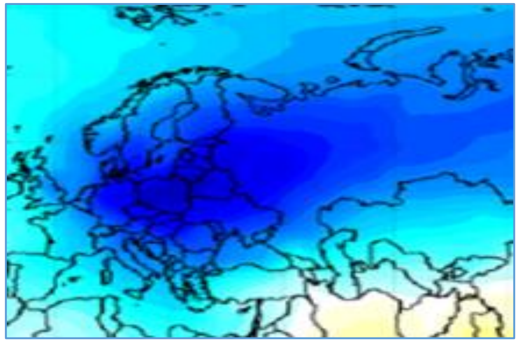
(Poliukhov et al., 2019)

Since the sulphate aerosol has decreased significantly since 1980 it should be a pronounced increase in cloud radiative transmittance due to the first non-direct effect.

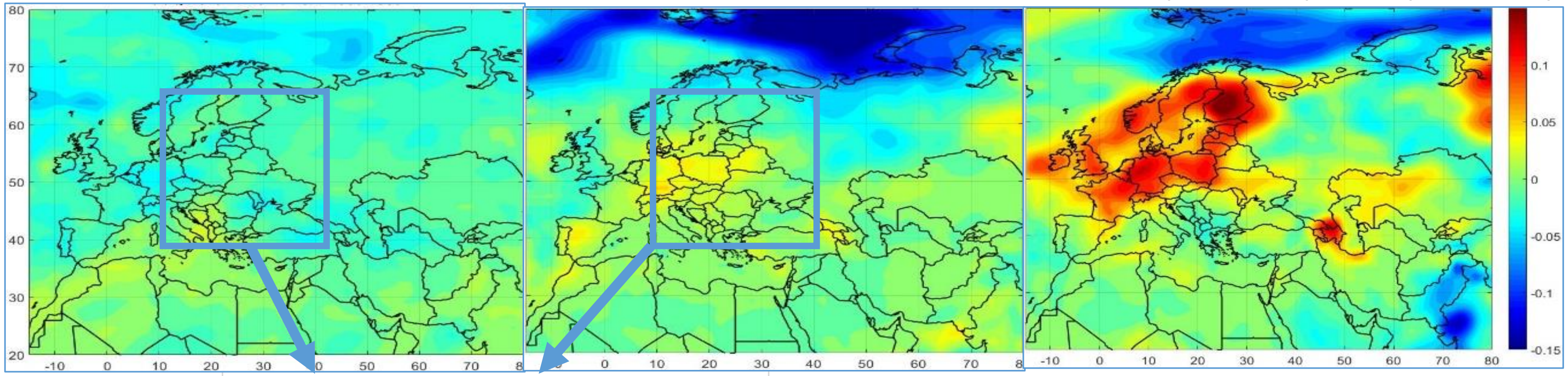
The changes in cloud radiative transmittance between 2005 and 1980 (deltaCQ=CQ_{2005}-CQ_{1980}) according to INMCM5, and ERA-Interim reanalysis. Summer conditions

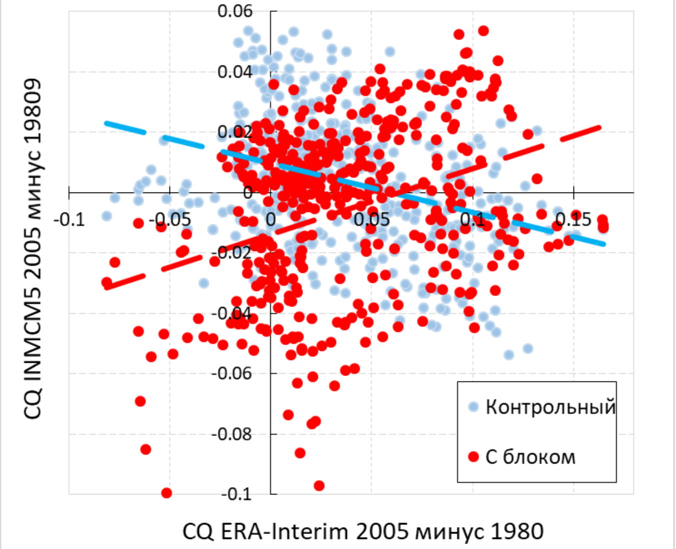
There is an increase up to 15% according to ERA-Interim

The changes in sulphate aerosol:



control INMCM5 experiment, no cloud-aerosol interaction | INMCM5 experiment with cloud-aerosol interaction | ERA-Interim summer (2004-2006) minus (1979-1981)





For the area of 40-65N 10-40E

Concluding remarks:

The account of cloud-aerosol interaction and the decrease in sulphate AOD provide an increase in cloud radiative transmittance (CQ) and improve the agreement with ERA-INTERIM dataset.

Similar results were obtained in comparisons with reconstruction model . This means that the effects are mainly due to changes in cloud amount.

Similar comparisons with the results from reconstruction model over several sites